# NEUTRINOS

## Science for the 21st Century *will include continuing research into the mysterious subatomic world of neutrinos*

The sun and other stars emit neutrinos constantly by fusing hydrogen into helium and yet Earth and other cosmic bodies are virtually transparent to them. Scientists calculate that approximately 3 trillion neutrinos pass through every square centimeter of Earth's surface every second, but only one in 10 billion ever interacts with other matter. These weak and rare interactions with other particles make neutrinos difficult to detect and study, but Los Alamos scientists have studied them with great success.

In 1955, Los Alamos scientists Frederick Reines and Clyde Cowan Jr. used a detector called "Herr Auge" or Mr. Eye, to gather the first tangible evidence of the existence of neutrinos, which previously had been known only in theory. This discovery earned Reines the 1995 Nobel Prize. In 1996 a team of scientists at Los Alamos used the Liquid Scintillator Neutrino Detector — a chamber filled with 60,000 gallons of pure mineral oil and 1,220 detectors — to demonstrate with a neutrinos created by a linear accelerator that the tiny particles might indeed have mass. At about the same time, Los Alamos researchers were leading SAGE, a joint Russian-American experiment using 55 tons of liquid gallium metal as a solar neutrino detector located deep underground in the Caucasus Mountains of Russia.

Today, Los Alamos scientists are pursuing neutrino research in locations around the world. The Liquid Scintillator Neutrino Detector experiment is moving to Fermi National Accelerator Laboratory. The Fermilab version of the Los Alamos experiment, called Boone, will provide further evidence to validate or refute the neutrino mass discovery.

In another project, Los Alamos scientists are among hundreds of international collaborators working in Japan's Kamioka mine on Super-Kamiokande, or Super-K — a huge cylindrical tank of purified water surrounded by eleven thousand detectors called photomultiplier tubes. Data from Super-K showed for the first time convincing evidence for neutrino oscillations. From these data scientists have gained a better understanding of neutrino mass, but the results raise many very deep questions about the properties of particles and their interactions.

Deep in the heart of Canada's Creighton mine lies the Sudbury Neutrino Observatory, a multinational collaboration includes researchers from Los Alamos. Located 6,800 feet below the surface, the Sudbury Neutrino Observatory contains 1,000 tons of heavy water in an acrylic vessel 12 meters in diameter. Interactions between incoming neutrinos and the heavy water are detected by the geodesic array of 9,600 photomultiplier tubes surrounding the vessel. Los Alamos researchers are developing ultra-sensitive detectors for SNO enabling it to uniquely prove that neutrinos produced in the sun have mass. Even a small amount of mass is enough to completely change our understanding of the neutrino.

Neutrino research has come a long way since Reines' and Cowan's first measurements. The Standard Model, a model that has ruled particle physics for nearly three decades, has as its cornerstone massless neutrinos. Since neutrino oscillations can only occur if neutrinos are massive, any detected oscillations constitute the first definite evidence of new physics beyond the Standard Model. Theoretical work at Los Alamos helps to elucidate the impact of these important new results, probes a much deeper understanding of how these elusive particles interact with material, and illuminates their importance in the cosmos. The neutrino's mass could eventually enable cosmologists to determine the origins and ultimate fate of the universe, as the combined mass of the wispy neutrinos could surpass the mass of all normal material in the universe.

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